L3- Angle Modulation-Part 1

Communications Principles (EE 322)

<u>Dr. Mohamed Ouda</u>
Electrical Engineering Department
College of Engineering
Al-Majmaa University

Angle Modulation

- Introduction to Angle Modulation
- Mathematical Analysis
- FM and PM Waveform
- Modulation Index and Percent Modulation
- Frequency and Bandwidth Analysis of Angle-Modulated Waves
- Deviation Ratio
- FM / PM Modulators
- Frequency-up Conversion in modulators

Introduction to Angle Modulation

- Angle modulation results whenever the phase angle, θ of a sinusoidal wave is varied with respect to time and can be expressed as

$$m(t) = V_c \cos\left[\omega_c t + \theta(t)\right] \qquad (1)$$

where $m(t)$ = angle-modulated wave

V_c = peak carrier amplitude

ω_c = carrier radian frequency

$\theta(t)$ = instantaneous phase deviation

where $\theta(t)$ is a function of the modulating signal given by

$$\theta(t) = F\left[V_m \sin(\omega_m t)\right] \qquad (2)$$

where ω_c = modulating signal radian frequency

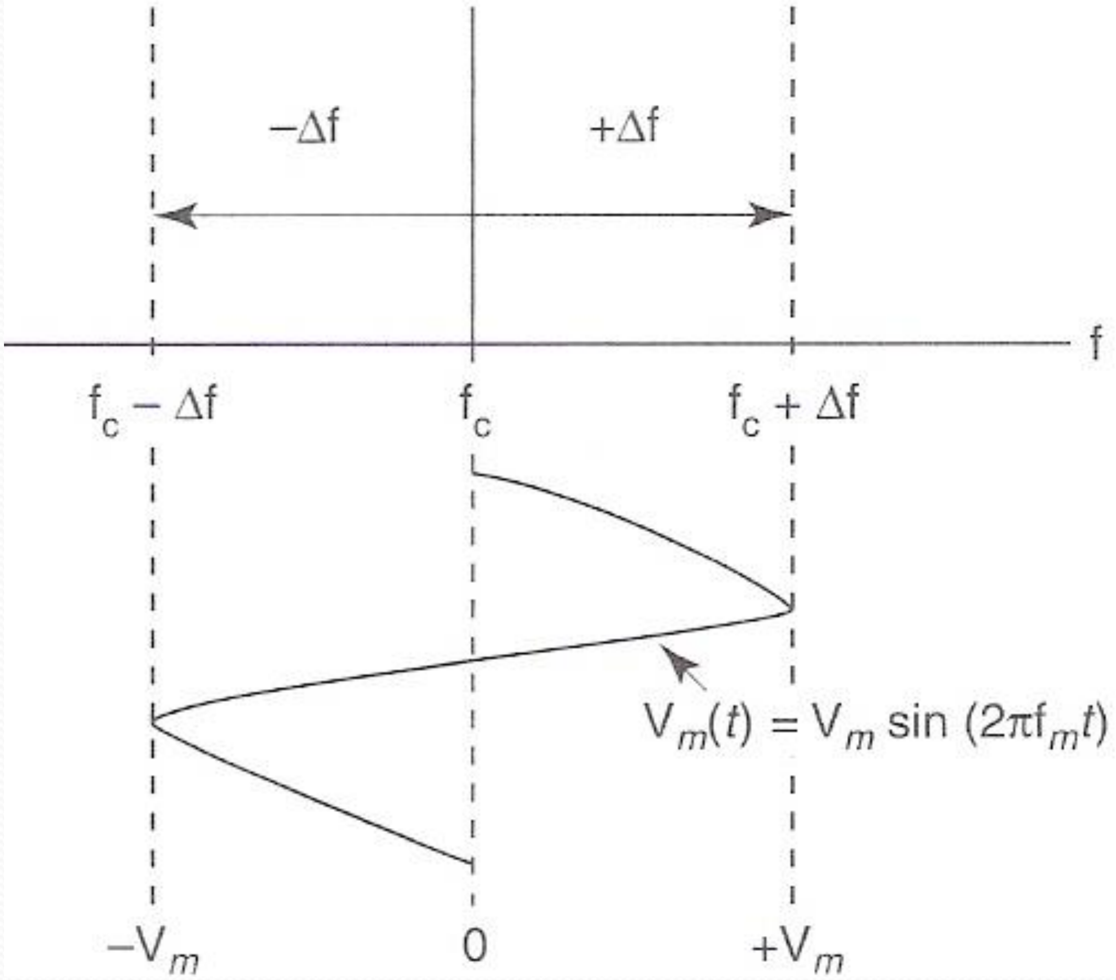
V_m = peak amplitude of the modulating signal

Introduction to Angle Modulation

- FM results when the frequency of the carrier is varied directly by the modulating signal
- PM results when the phase of the carrier is varied directly by the modulating signal
  - ***Frequency Modulation (FM)***
    - variation of the frequency of the modulating signal with constant amplitude
    - frequency variation is directly proportional to the amplitude of the modulating signal
    - rate of variation equal to the frequency of the modulating signal
  - ***Phase Modulation (PM)***
    - variation of the phase of the modulating signal with constant amplitude
    - phase variation is directly proportional to the amplitude of the modulating signal
    - rate of variation equal to the frequency of the modulating signal

Angle Modulation Representation in Freq. and Time Domain

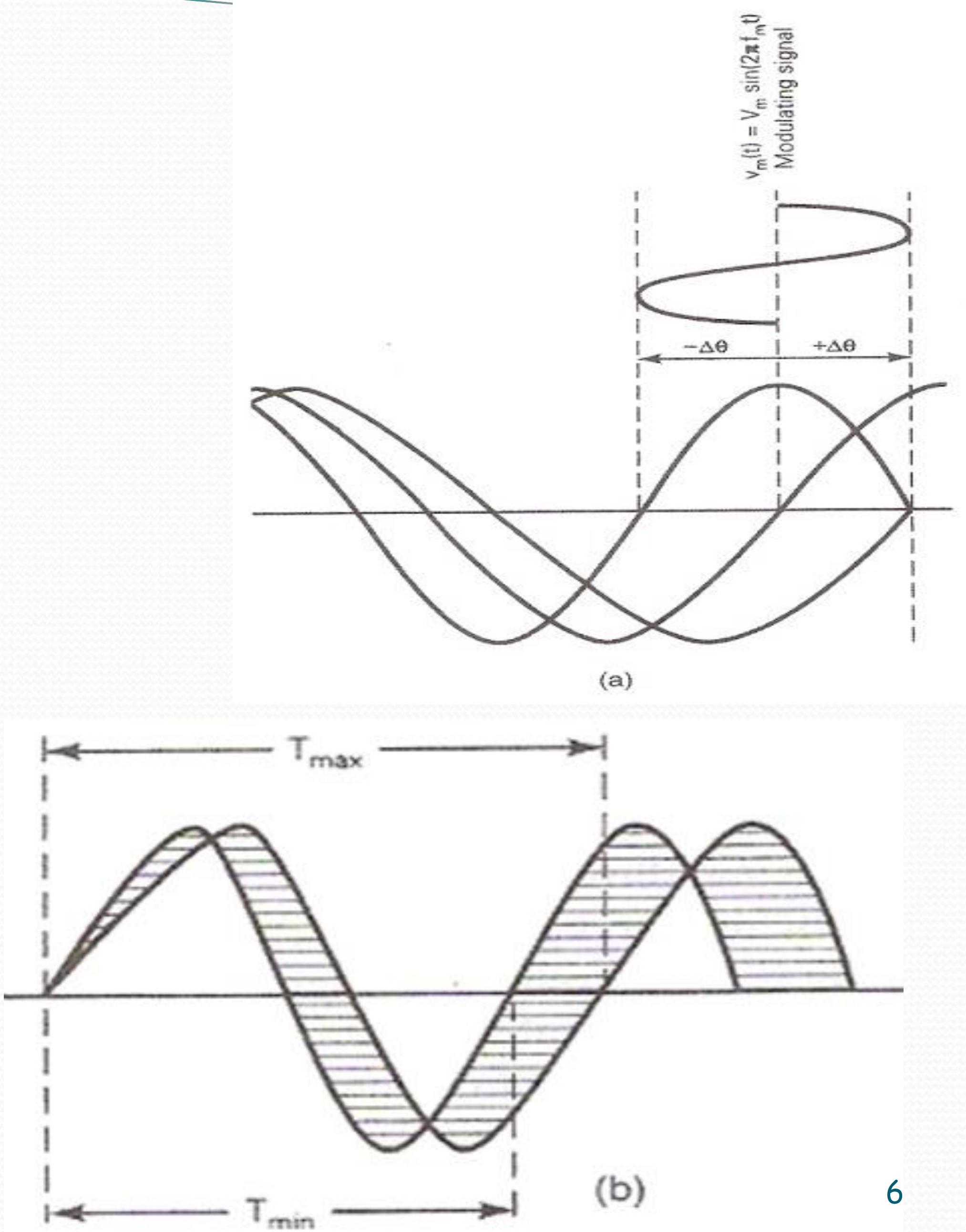
- An angle modulated signal in the frequency domain :
  - the carrier frequency, f_c is changed when acted on by the modulating signal.
  - the magnitude and direction of the frequency deviation, Δf is proportional to the amplitude and polarity of the modulating signal.



Angle Modulation Representation in Freq. and Time Domain

- An angle modulated signal in the time domain :
  - the phase of the carrier is changing proportional to the amplitude of the modulating signal.
  - the phase shift is called phase deviation *Δθ*. This shift is also produces a corresponding change in the frequency, known as frequency deviation *Δf*.
  - peak-to-peak frequency deviation is determine by (as shown in figure (b)),

$$\Delta f_{p-p} = \frac{1}{T_{min}} - \frac{1}{T_{max}} \qquad (3)$$



Mathematical Analysis

- to differentiate between FM and PM, the following terms need to be defined :
  - ***1. Instantaneous Phase Deviation***
    - the instantaneous change in the phase of the carrier at a given instant of time.

  Instantaneous phase deviation = $\theta(t)$ rad **(4)**

  - ***2. Instantaneous phase***
    - the precise phase of the carrier at a given instant of time.

  Instantaneous phase = $\omega ct + \theta(t)$ rad **(5)**

  - ***3. Instantaneous frequency deviation***
    - the instantaneous change in the frequency of the carrier and is defined as the first time derivative of the instantaneous phase deviation.

  Instantaneous frequency deviation = $\theta'(t)$ rad/s **(6)**

  - ***4. Instantaneous frequency***
    - the precise frequency of the carrier at a given instant of time and is defined as the first time derivative of the instantaneous phase.

  Instantaneous frequency = $\omega i = \omega c + \theta'(t)$ rad/s **(7)**

Mathematical Analysis

- from the previous 4 terms, (3) ~ (7), PM and FM can be defined as :
  - PM : an angle modulation in which θ(t) is proportional to the amplitude of the modulating signal.
  - FM : an angle modulation in which θ'(t) is proportional to the amplitude of the modulating signal.
- For a modulating signal $v_m(t)$,

$$\theta(t) = K v_m(t) \text{ rad} \qquad \textbf{(8)}$$

$$\theta'(t) = K_1 v_m(t) \text{ rad/s} \qquad \textbf{(9)}$$

where K and K_1 are constants and are the *deviation sensitivities* of the phase and frequency modulators, respectively.

Mathematical Analysis

- substituting a modulating signal $v_m(t) = V_m cos(\omega_\mathrm{m} t)$, equation (8) and (9) into equation (1) yields

PM :

$$m(t) = V_c \cos[\omega_c t + \theta(t)]$$

$$= V_c \cos[\omega_c t + KV_m \cos(\omega_m t)] \qquad (10)$$

FM : as $\theta(t) = \int \theta'(t)$

$$m(t) = V_c \cos\left[\omega_c t + \int \theta'(t)\right]$$

$$= V_c \cos\left[\omega_c t + K_1 \int V_m \cos(\omega_m t) dt\right]$$

$$= V_c \cos\left[\omega_c t + \frac{K_1 Vm}{\omega_m} \sin(\omega_m t)\right] \qquad (11)$$

Mathematical Analysis

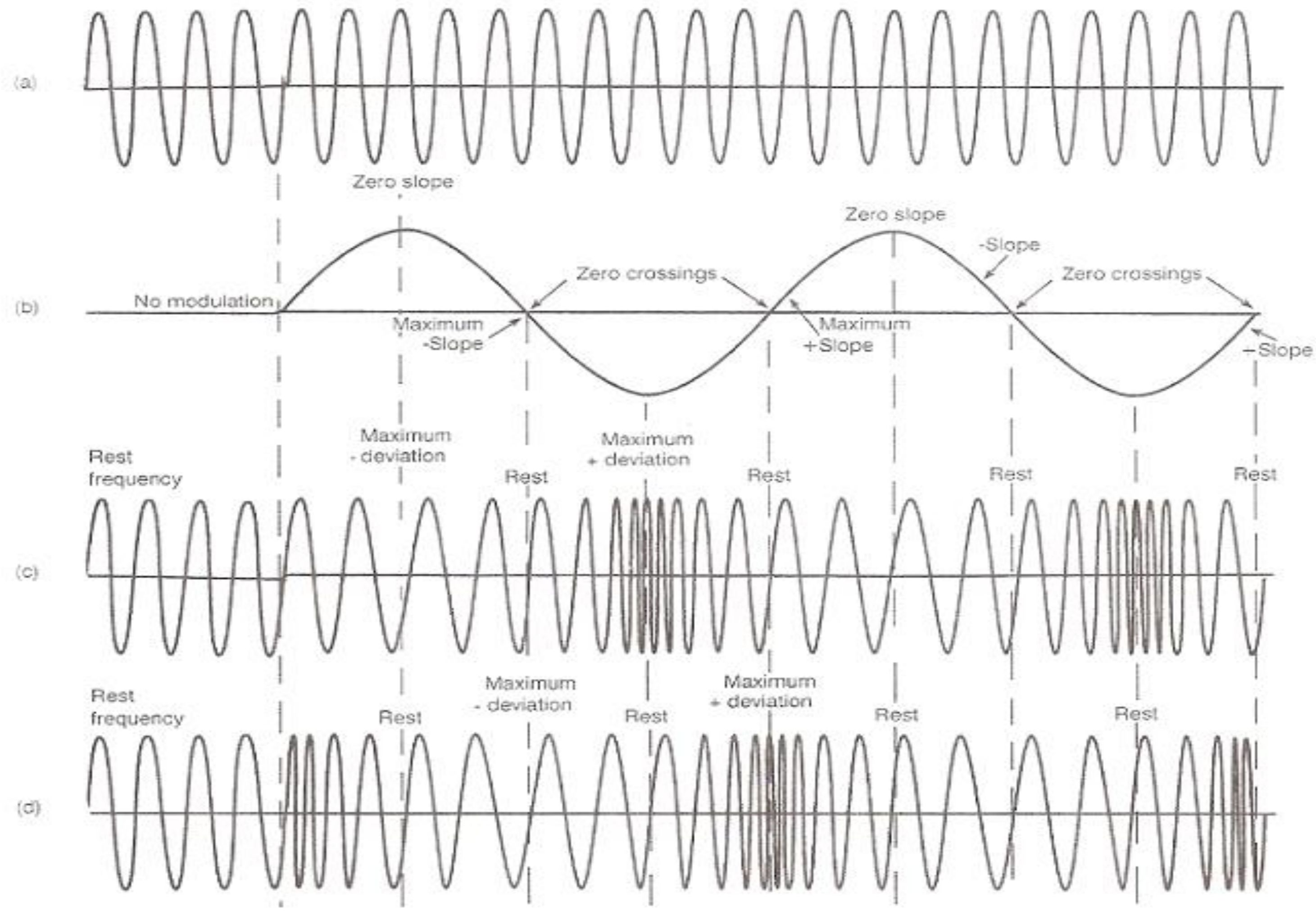
- Summarized table :

Table 7-1 Equations for Phase- and Frequency-Modulated Carriers

Type of Modulation	Modulating Signal	Angle-Modulated Wave, $m(t)$
(a) Phase	$v_m(t)$	$V_c \cos[\omega_c t + K v_m(t)]$
(b) Frequency	$v_m(t)$	$V_c \cos[\omega_c t + K_1 \int v_m(t)\, dt]$
(c) Phase	$V_m \cos(\omega_m t)$	$V_c \cos[\omega_c t + K V_m \cos(\omega_m t)]$
(d) Frequency	$V_m \cos(\omega_m t)$	$V_c \cos\left[\omega_c t + \frac{K_1 V_m}{\omega_m} \sin(\omega_m t)\right]$

FM and PM Waveforms

- Waveforms of FM and PM of a sinusoidal carrier by a single-frequency modulating signal.

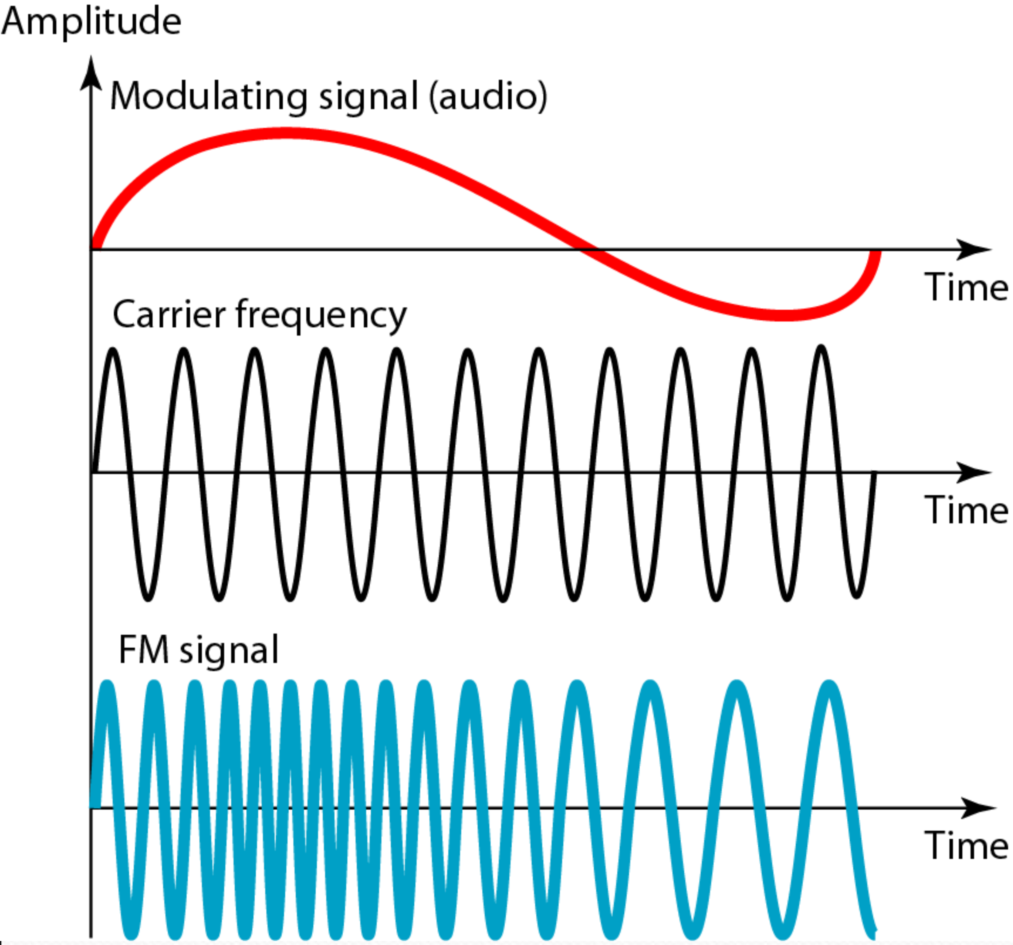


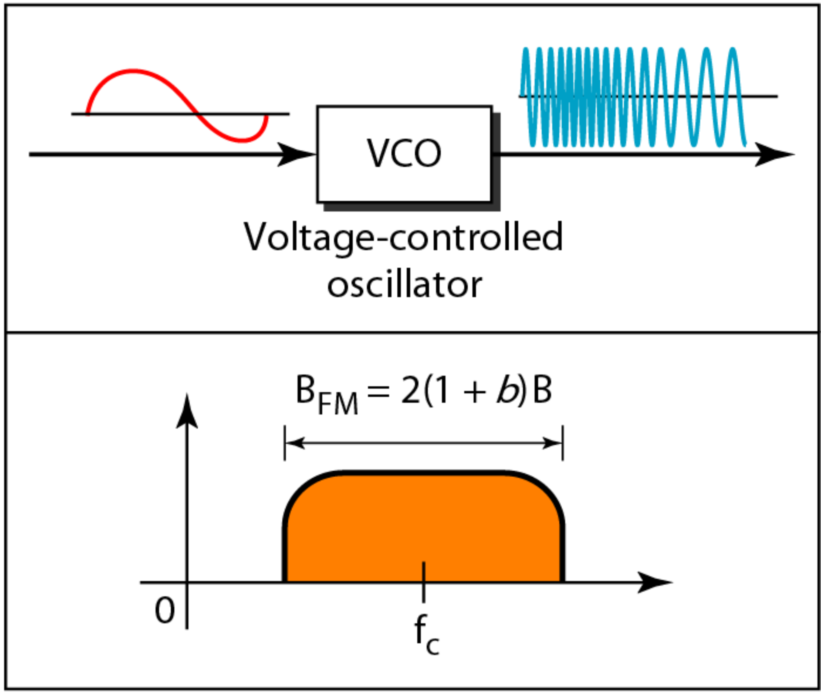
Phase and frequency modulation of a sine-wave carrier by a sine-wave signal: (a) unmodulated carrier; (b) modulating signal; (c) frequency-modulated wave; (d) phase-modulated wave

FM and PM Waveforms

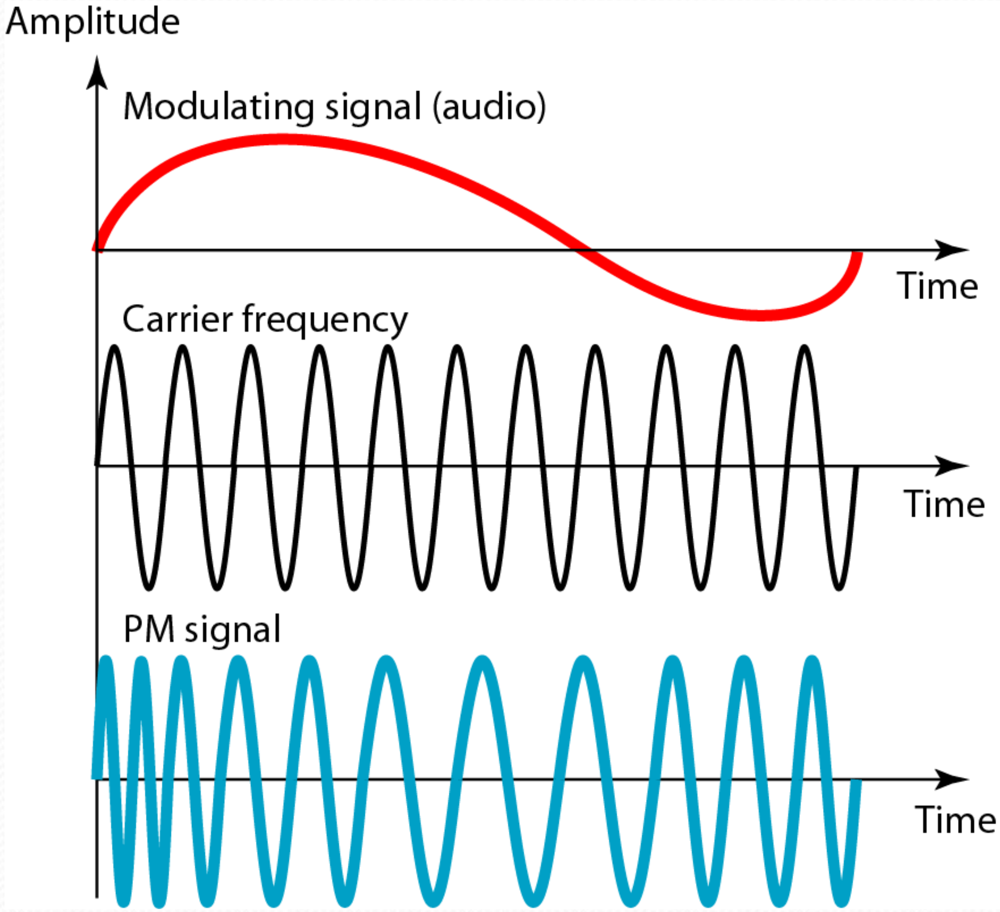
- FM and PM waveforms are identical except for their time relationship.
- for FM, the maximum frequency deviation occurs during the maximum positive and negative peaks of the modulating signal.
- for PM, the maximum frequency deviation occurs during the zero crossings of the modulating signal (i.e. the frequency deviation is proportional to the slope of first derivative of the modulating signal).

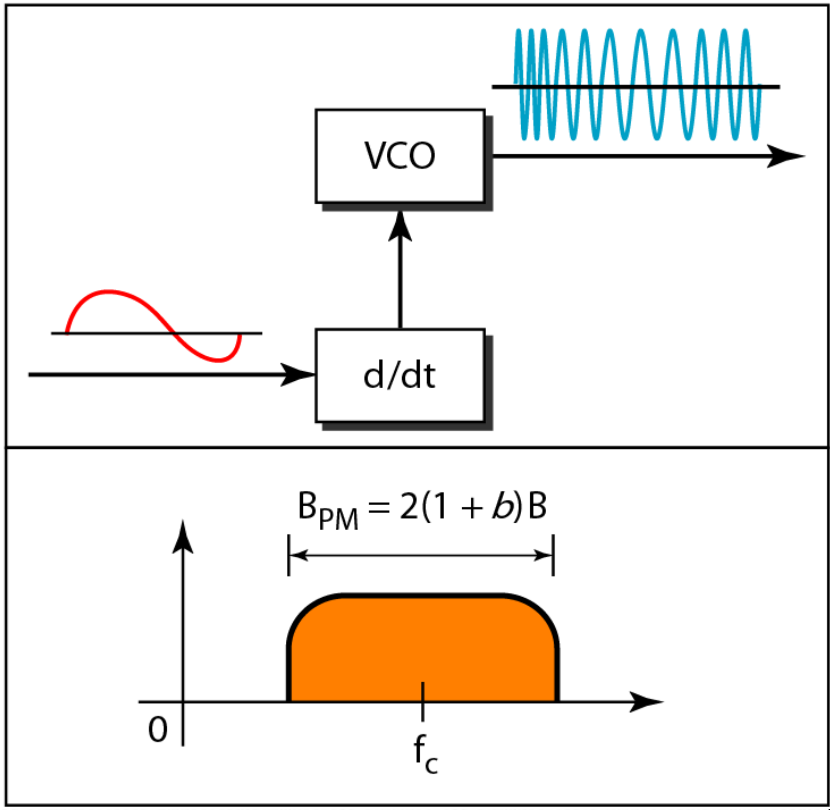
Frequency modulation





Phase modulation





Modulation Index and Percent Modulation

- comparing equation (10) and (11), equation (1) can be rewritten in general form as

$$m(t) = V_c \cos\left[\omega_c t + m\cos(\omega_m t)\right] \qquad (12)$$

where *m* is called the modulation index.

Modulation Index and Percent Modulation for PM

- for PM, the modulation index is also known as *peak phase deviation Δθ*, and is proportional to the amplitude of the modulating signal and is expressed as

$$m = \Delta\theta = KV_m(radians) \qquad (13)$$

where m = modulation index
K = deviation sensitivity (radians/volt)
V_m = peak modulating signal amplitude (volt)

Modulation Index and Percent Modulation for PM

- therefore, for PM :

$$m(t) = V_c \cos\left[\omega_c t + K V_m \cos(\omega_m t)\right]$$
$$= V_c \cos\left[\omega_c t + \Delta\theta \cos(\omega_m t)\right]$$
$$= V_c \cos\left[\omega_c t + m \cos(\omega_m t)\right] \qquad (14)$$

Modulation Index and Percent Modulation for FM

- for FM, the modulation index is directly proportional to the amplitude of the modulating signal and inversely proportional to the frequency of the modulating signal.

$$m = \frac{K_1 V_m}{\omega_m} = \frac{K_1 V_m}{f_m} (unitless) \qquad (15)$$

where $\mathbf{K_1}$ = deviation sensitivities (radians/second per volt or cycles/second per vol

Vm = peak modulating signal amplitude (volt)

$\boldsymbol{\omega_m}$ = radian frequency (radians/second)

$\mathbf{f_m}$ = cyclic frequency (cycles/second or hertz)

Modulation Index and Percent Modulation for FM

- also for FM, the peak frequency deviation Δf is simply the product of the deviation sensitivity and the peak modulating signal voltage. I.e.

$$\Delta f = K_1 V_m \Rightarrow m = \frac{\Delta f}{f_m} (unitless) \qquad (16)$$

- therefore, for FM, equation (11) can be rewritten as

$$m(t) = V_c \cos\left[\omega_c t + \frac{K_1 V_m}{f_m}\sin(w_m t)\right]$$

$$= V_c \cos\left[\omega_c t + \frac{\Delta f}{f_m}\sin(w_m t)\right]$$

$$= V_c \cos[\omega_c t + m \sin(w_m t)] \qquad (17)$$

Modulation Index and Percent Modulation for FM

- Summarized :

Table 7-2 Angle Modulation Summary

	FM	PM
Modulated wave	$m(t) = V_c \cos\left[\omega_c t + \frac{K_1 V_m}{f_m}\sin(\omega_m t)\right]$	$m(t) = V_c \cos[\omega_c t + KV_m \cos(\omega_m t)]$
or	$m(t) = V_c \cos[\omega_c t + m \sin(\omega_m t)]$	$m(t) = V_c \cos[\omega_c t + m \cos(\omega_m t)]$
or	$m(t) = V_c \cos\left[\omega_c t + \frac{\Delta f}{f_m}\sin(\omega_m t)\right]$	$m(t) = V_c \cos[\omega_c t + \Delta\theta \cos(\omega_m t)]$
Deviation sensitivity	K_1 (Hz/V)	K (rad/V)
Deviation	$\Delta f = K_1 V_m$ (Hz)	$\Delta\theta = KV_m$ (rad)
Modulation index	$m = \frac{K_1 V_m}{f_m}$ (unitless)	$m = KV_m$ (rad)
or	$m = \frac{\Delta f}{f_m}$ (unitless)	$m = \Delta\theta$ (rad)
Modulating signal	$v_m(t) = V_m \sin(\omega_m t)$	$v_m(t) = V_m \cos(\omega_m t)$
Modulating frequency	$\omega_m = 2\pi f_m$ rad/s	$\omega_m = 2\pi f_m$ rad/s
or	$\omega_m/2\pi = f_m$ (Hz)	$\omega_m/2\pi = f_m$ (Hz)
Carrier signal	$V_c \cos(\omega_c t)$	$V_c \cos(\omega_c t)$
Carrier frequency	$\omega_c = 2\pi f_c$ (rad/s)	$\omega_c = 2\pi f_c$ (rad/s)
or	$\omega_c/2\pi = f_c$ (Hz)	$\omega_c/2\pi = f_c$ (Hz)

Percent Modulation

- percent modulation for angle modulation is determined in different manner than for amplitude modulation.

- with angle modulation, percent modulation is the ratio of frequency deviation actually produced to the maximum frequency deviation allowed, stated in percent form

$$Percent\ modulation = \frac{\Delta f_{(actual)}}{\Delta f_{(\max)}} \times 100\% \qquad (18)$$

Example 1

- A 107.6 MHz carrier frequency modulated by a 7 KHz sine wave. The resultant FM signal has a frequency deviation of 50KHz.
- A) find the carrier swing of the FM signal

$$\text{c.s.} = 2\Delta f = 2 \times 50 \times 10^3 = 100\,\text{kHz}$$

- B) Determine the highest and lowest frequency attained by the modulated signal

$$f_H = f_c + \Delta f = 107.6 \times 10^6 + 50 \times 10^3$$
$$= (107\,600 \times 10^3) + (50 \times 10^3) = 107.65\,\text{MHz}$$

$$f_L = f_c - \Delta f = 107.6 \times 10^6 - 50 \times 10^3$$
$$= 107\,600 \times 10^3 - 50 \times 10^3 = 107.55\,\text{MHz}$$

- C) what is the modulation index of the FM wave

$$m_f = \frac{\Delta f}{f_a} = \frac{50 \times 10^3}{7 \times 10^3} = 7.143$$

Example 2

- An FM transmission has a frequency deviation of 20kHz
- A) Determine the percent modulation of this signal if it is broadcast in the 88-108 MHz band, Given Δf_{max}=75kHz

$$M = \frac{\Delta f_{\text{actual}}}{\Delta f_{\text{max}}} \times 100 = \frac{20 \times 10^3}{75 \times 10^3} \times 100 = 26.67\%$$

- B) Calculate the percent modulation if this signal were broadcast as the audio portion of a television broadcast, Given Δf_{max}=25kHz

$$M = \frac{\Delta f_{\text{actual}}}{\Delta f_{\text{max}}} \times 100 = \frac{20 \times 10^3}{25 \times 10^3} \times 100 = 80.0\%$$

Frequency and Bandwidth Analysis of Angle-Modulated Waves

- in PH, FM, a modulating signal produces an infinite number of side frequencies pairs (i.e. it has infinite band width frequency).

Bessel Function

- from equation (12), the angle-modulated wave is expressed as

$$m(t) = V_c \cos[\omega_c t + m \cos(\omega_m t)]$$

- based on the above equation, the individual frequency components of the angle-modulated wave is not obvious.
- Bessel function identities can be used to determine the side frequencies components

$$\cos(\alpha + m \cos \beta) = \sum_{n=-\infty}^{\infty} J_n(m) \cos(\alpha + n\beta + \frac{n\pi}{2}) \quad (19)$$

where $J_n(m)$ is the Bessel function of the first kind.

- applying equation (19) to equation (12) yields,

$$m(t) = Vc \sum_{n=-\infty}^{\infty} J_n(m) \cos(\omega_c t + n\omega_m t + \frac{n\pi}{2}) \quad (20)$$

Bessel Function

- expanding (20),

$$m(t) = V_c \left\{ J_0(m)\cos(\omega_c t) + J_1(m)\cos\left[(\omega_c + \omega_m)t + \frac{\pi}{2}\right] \right.$$

$$- J_1(m)\cos\left[(\omega_c - \omega_m)t - \frac{\pi}{2}\right] + J_2(m)\cos\left[(\omega_c + 2\omega_m)t\right]$$

$$\left. + \ldots Jn(m) \ldots \right\}$$

where *m(t)* = angle modulated wave

m = modulation index

V_c = peak carrier amplitude

$J_0(m)$ = carrier component

$J_1(m)$ = first set of side frequencies displaced from carrier by ω_m

$J_n(m)$ = *nth* set of side frequencies displaced from carrier by $n\,\omega_m$

- in other words, angle modulation produces infinite number of sidebands, called as first-order sidebands, second-order sidebands, and so on. Also their magnitude are determined by the coefficients J_1(m), J_2(m),…J_n(m).

Bessel Function

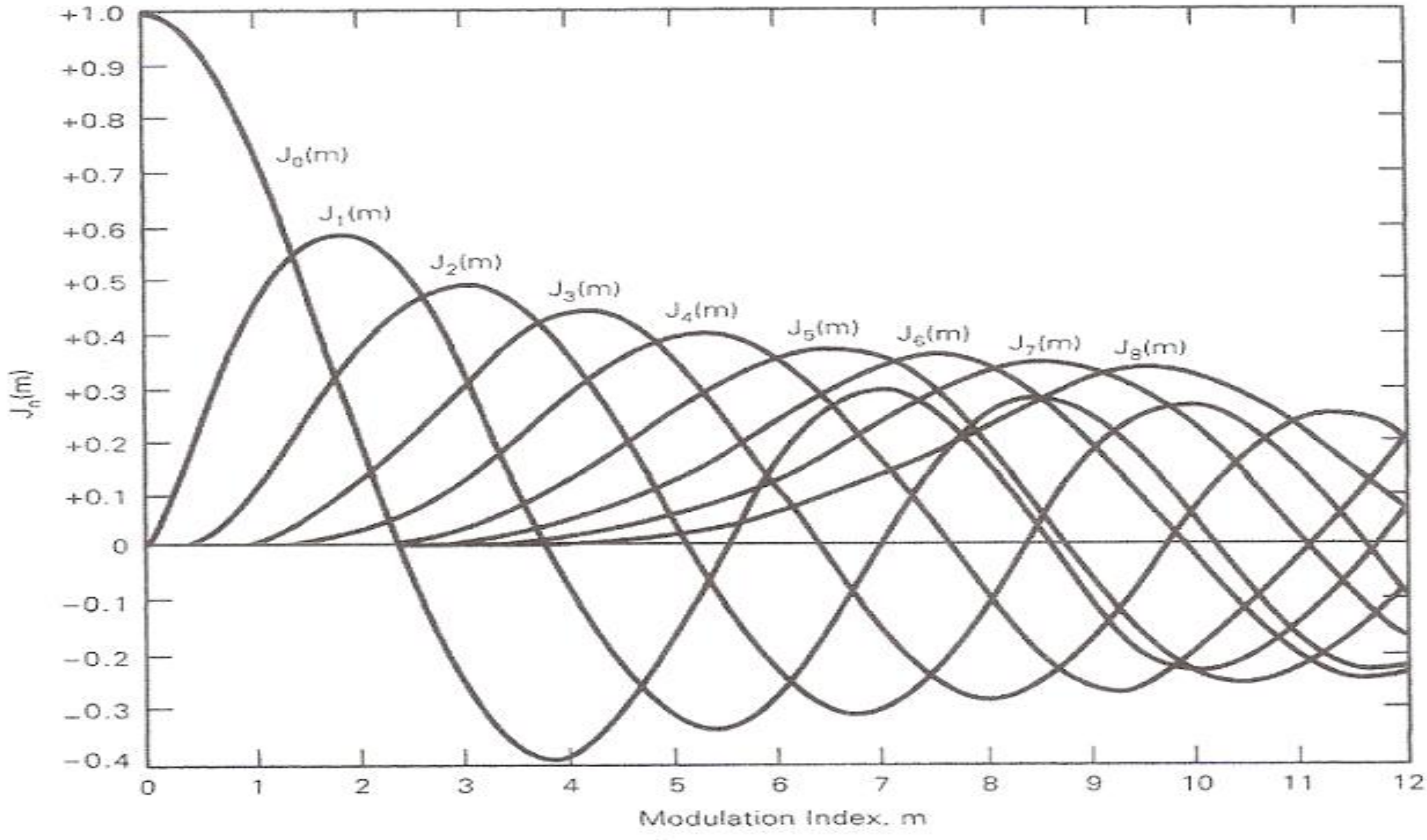
- Bessel function of the first kind for several values of modulation index.

x	*n* OR ORDER																
	(CARRIER)	(Sidebands)															
(m_f)	J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9	J_{10}	J_{11}	J_{12}	J_{13}	J_{14}	J_{15}	J_{16}
0.00	1.00	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0.25	0.98	0.12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0.5	0.94	0.24	0.03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.0	0.77	0.44	0.11	0.02	—	—	—	—	—	—	—	—	—	—	—	—	—
1.5	0.51	0.56	0.23	0.06	0.01	—	—	—	—	—	—	—	—	—	—	—	—
2.0	0.22	0.58	0.35	0.13	0.03	—	—	—	—	—	—	—	—	—	—	—	—
2.5	−0.05	0.50	0.45	0.22	0.07	0.02	—	—	—	—	—	—	—	—	—	—	—
3.0	−0.26	0.34	0.49	0.31	0.13	0.04	0.01	—	—	—	—	—	—	—	—	—	—
4.0	−0.40	−0.07	0.36	0.43	0.28	0.13	0.05	0.02	—	—	—	—	—	—	—	—	—
5.0	−0.18	−0.33	0.05	0.36	0.39	0.26	0.13	0.05	0.02	—	—	—	—	—	—	—	—
6.0	0.15	−0.28	−0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02	—	—	—	—	—	—	—
7.0	0.30	0.00	−0.30	−0.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02	—	—	—	—	—	—
8.0	0.17	0.23	−0.11	−0.29	−0.10	0.19	0.34	0.32	0.22	0.13	0.06	0.03	—	—	—	—	—
9.0	−0.09	0.24	0.14	−0.18	−0.27	−0.06	0.20	0.33	0.30	0.21	0.12	0.06	0.03	0.01	—	—	—
10.0	−0.25	0.04	0.25	0.06	−0.22	−0.23	−0.01	0.22	0.31	0.29	0.20	0.12	0.06	0.03	0.01	—	—
12.0	0.05	−0.22	−0.08	0.20	0.18	−0.07	−0.24	−0.17	0.05	0.23	0.30	0.27	0.20	0.12	0.07	0.03	0.01
15.0	−0.01	0.21	0.04	−0.19	−0.12	0.13	0.21	0.03	−0.17	−0.22	−0.09	0.10	0.24	0.28	0.25	0.18	0.12

Source: E. Cambi, *Bessel Functions*, Dover Publications, Inc., New York, 1948. Courtesy of the publisher.

Bessel Function

- Curves for the relative amplitudes of the carrier and several sets of side frequencies for values of *m* up to 10.



$J_n(m)$ versus m

Bessel Function

❖ Conclusion from the table & graph :

- modulation index m of 0 produces zero side frequencies.
- the larger the m, the more sets of side frequencies are produced.
- values shown for J_n are relative to the amplitude of the unmodulated carrier.
- as the m decreases below unity, the amplitude of the higher-order side frequencies rapidly becomes insignificant.
- as the m increases from 0, the magnitude of the carrier $J_0(m)$ decreases.
- the negative values for J_n simply indicate the relative phase of that side frequency set
- a side frequency is not considered significant unless its amplitude is equal or greater that 1% of the unmodulated carrier amplitude ($J_n \geq 0.01$).
- as m increases, the number of significant side frequencies increases. I.e. the bandwidth of an angle-modulated wave is a function of the modulation index.

Bandwidth Requirement

- angle-modulated wave consumes larger bandwidth than an AM wave.
- bandwidth of an angle-modulated wave is a function of the modulating signal and the modulation index.
- the actual bandwidth required to pass all the significant sidebands for an angle-modulated wave is equal to 2 times the product of the highest modulating signal frequency and the number of significant sidebands determined from the table of Bessel function.
  - I.e. the minimum bandwidth for angle-modulated wave using the Bessel table,

$$B = 2(n \times f_m) Hz \qquad (21)$$

Carson's Rule

- it is a general rule to estimate the bandwidth for all angle-modulated systems regardless of the modulation index.
- the Carson's Rule states that the bandwidth necessary to transmit an angle-modulated wave as twice the sum of the peak frequency deviation and the highest modulating signal frequency.
-

$$B = 2(\Delta f + f_m) Hz \qquad (22)$$

Bandwidth Requirement

❖ Carson's Rule

❖ for a low modulation index (f_m is much larger than Δf),

$$B = 2 f_m (Hz) \tag{23}$$

This is called **Narrowband FM**

❖ for a high modulation index (Δf is much larger than f_m)

$$B = 2\Delta f\,(Hz) \tag{24}$$

❖ Carson's Rule approximate and gives a narrower bandwidth than the bandwidth determined using Bessel function. Therefore, a system designed using Carson's Rule would have a narrower bandwidth but a poorer performance than system designed using the Bessel table.

❖ for modulation index above 5, Carson's Rule is a close approximation to the actual bandwidth required.

Deviation Ratio

- ***Deviation ratio DR*** is the worst case modulation index and is equal to the maximum peak frequency deviation divided by the maximum modulating-signal frequency – producing the widest frequency spectrum.

$$DR = \frac{\Delta f_{(\max)}}{f_{m(\max)}}$$

where DR = deviation ratio (unitless)

$\Delta f_{(max)}$ = maximum peak frequency deviation (Hertz)

$f_{m(max)}$ = maximum modulating-signal frequency (Hertz)

Example 3

Determine the deviation ratio and bandwidth for the worst-case (widest bandwidth) modulation index for an FM broadcast-band transmitter with a maximum frequency deviation of 75 kHz and a maximum modulating-signal frequency of 15 kHz.

$$DR = \frac{75kHz}{15kHz} = 5$$

From Bessel Table, a modulation index of 5 produces 8 significant sidebands

Thus, the bandwidth is

B = 2(8 x 15000) = 240 kHz

Example 4

For a 37.5 kHz frequency deviation and a modulating-signal frequency fm = 7.5 kHz, the modulation index is

$$m = \frac{37.5kHz}{7.5kHz} = 5$$

and the bandwidth is B = 2(8 x 7500) = 120 kHz

Deviation Ratio

- From Ex. a & b, although the same modulation index (5) was achieved with 2 different modulating-signal frequencies and amplitudes, 2 different bandwidths were produced.
- The widest bandwidth will only be produced from the maximum modulating-signal frequency and maximum frequency deviation.
- The same condition applies in the case of using the Carson's rule :

$$B = 2\left[\Delta f_{(\max)} + f_{m(\max)}\right] \qquad = 2\left(75kHz + 15kHz\right) = 180kHz$$

FM/PM Modulators

❖ a phase modulator is a circuit in which the carrier instantaneous phase is proportional to the modulating signal.

❖ a frequency modulator is a circuit in which the carrier instantaneous phase is proportional to the integral of the modulating signal.

PM modulator : $\theta(t) \propto v(t)$

FM modulator : $\theta(t) \propto \int v(t)$

Wideband Frequency Modulation –

- If the modulation index is higher than 10, then it is called wideband FM.
- Spectrum contains infinite numbers of sidebands and carrier as against two sidebands and carrier in NBFM.
- BW is = $2\{\Delta fm_{(max)}\}$ as against 2fm for NBFM.
- Used for broadcast and entertainment as against for mobile communication for NBFM.

Advantages of Angle Modulation over AM-

1. As the amplitude of FM carrier is constant, the noise interference is minimum.
2. The amplitude of FM carrier is constant and is independent of depth of modulation. Hence transmitter power remains constant in FM whereas it varies in AM.
3. As against the limitation of depth of modulation in AM, in FM depth of modulation can be increased to any value, without causing any distortion.

Advantages of Angle Modulation over AM

- 4. Because of guard bands provided in FM, adjacent channel interference is very less.
- 5. Since FM uses VHF and UHF bands of frequencies, the noise interference is minimum as compared to AM which uses MF and HF ranges.
- 6. Radius of propagation is limited as FM uses space waves with line of sight. So it is possible to operate many independent transmitters on the same frequency with minimum interference.

Disadvantages of FM compared to AM-

- 1. BW requirement of FM is very high as compared to AM.
- 2. FM equipments are more complex and hence costly.
- Area covered by FM is limited, to line of sight area but AM coverage area is large.

Comparison between FM and AM

Parameter	AM	FM
Origin	AM method of audio transmission was first successfully carried out in the mid 1870s.	FM radio was developed in the United states mainly by Edwin Armstrong in the 1930s.
Modulating differences	In AM, a radio wave known as the "carrier" or "carrier wave" is modulated in amplitude by the signal that is to be transmitted	In FM, a radio wave known as the "carrier" or "carrier wave" is modulated in frequency by the signal that is to be transmitted.
Importance	It is used in both analog and digital communication and telemetry	It is used in both analog and digital communication and telemetry
Frequency Range	AM radio ranges from 535 to 1705 KHz (OR) Up to 1200 Bits per second.	FM radio ranges in a higher spectrum from 88 to 108 MHz. (OR) 1200 to 2400 bits per second.

Comparison between FM and AM

Parameter	AM	FM
Bandwidth Requirements	Twice the highest modulating frequency. In AM radio broadcasting, the modulating signal has bandwidth of 15kHz, and hence the bandwidth of an amplitude-modulated signal is 30kHz.	Twice the sum of the modulating signal frequency and the frequency deviation. If the frequency deviation is 75kHz and the modulating signal frequency is 15kHz, the bandwidth required is 180kHz.
Complexity	Transmitter and receiver are simple but synchronization is needed in case of SSBSC AM carrier.	Transmitter and receiver are more complex as variation of modulating signal has to be converted and detected from corresponding variation in frequencies.(i.e. voltage to frequency and frequency to voltage conversion has to be done).
Noise	AM is more susceptible to noise because noise affects amplitude, which is where information is "stored" in an AM signal.	FM is less susceptible to noise because information in an FM signal is transmitted through varying the frequency, and not the amplitude.

Comparison between FM and AM

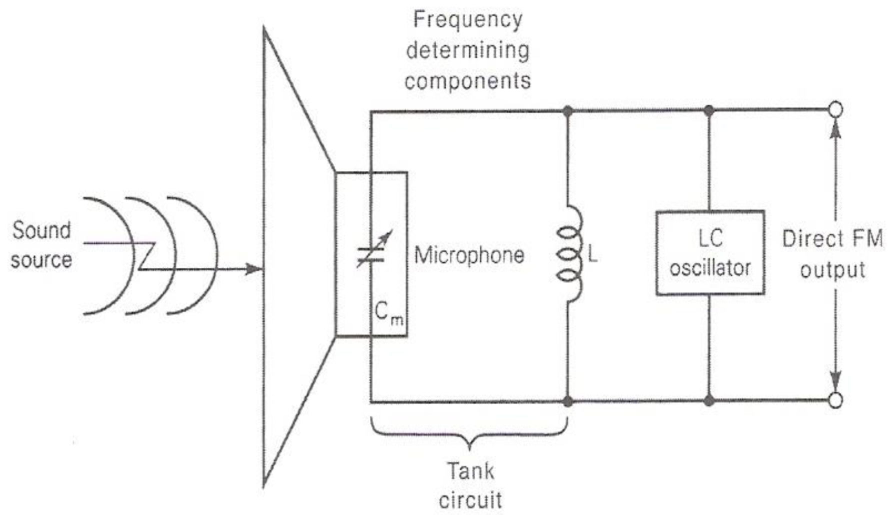
Sr No.	FM	PM
1	The max frequency deviation depends on amplitude of modulating signal and its frequency	The max phase deviation depends on amplitude of modulating signal
2	Frequency of the carrier is modulated by modulating signal.	Phase of the carrier is modulated by modulating signal.
3	Modulation index is increased as modulation frequency is reduced and vice versa.	Modulation index remains same if modulating signal frequency is change.

Types of FM Modulators

1) Indirect FM – Modulation is obtained by phase modulation of the carrier.

2) Direct FM- The frequency of carrier is varied directly by modulating signal.

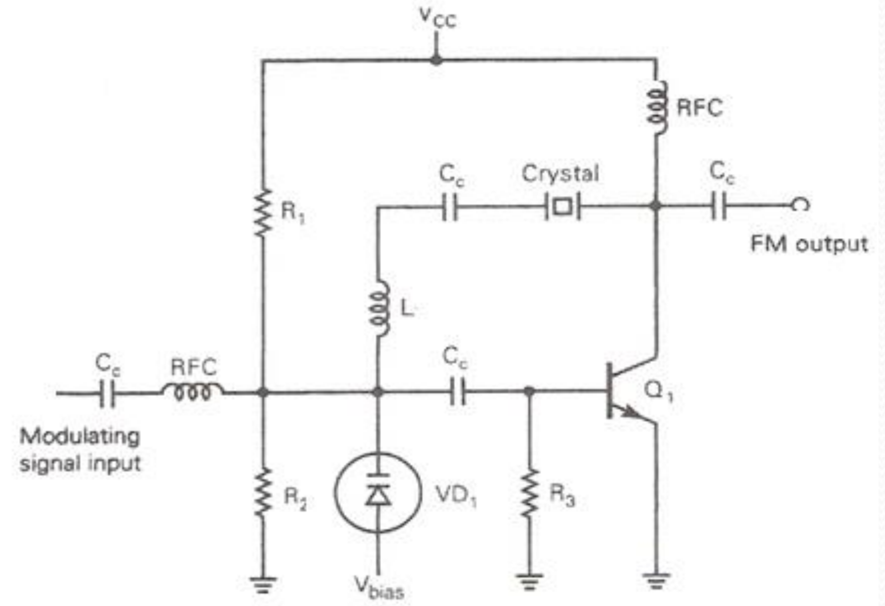
Direct Method



- A sinusoidal oscillator, with one of the reactive elements in the tank circuit of the oscillator being directly controllable by the message signal
- The tendency for the carrier frequency to drift, which is usually unacceptable for commercial radio applications.
- To overcome this limitation, frequency stabilization of the FM generator is required, which is realized through the use of feed-back around the oscillator

Direct Method -Varactor diode modulator

- Using varactor diode to deviate the frequency of a crystal oscillator :

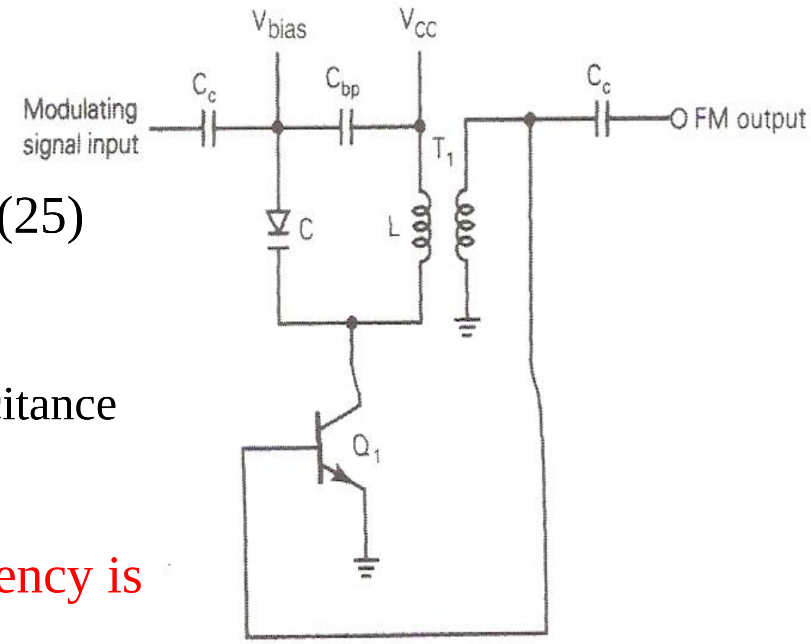


- R_1 and R_2 develop a DC voltage that reverse bias the varactor diode VD_1 and determine the resonant frequency of the oscillator.
- external modulating signal voltage added or subtracted from the DC bias, which changes the capacitance of the diode and consequently changes the frequency of the oscillation.

- positive alternations of the modulating signal increase the reverse bias of VD_1, which decrease its capacitance and increase the frequency of the oscillation.
- negative alternations of the modulating signal decrease the reverse bias of VD_1, which increase its capacitance and decrease the frequency of the oscillation.
- simple to use, stable and reliable but limited peak frequency deviation thus limited use to the low index applications.

VCO FM Modulator

- the use of varactor diode to transform changes in modulating signal amplitude to changes in frequency :



❖ the center frequency for the oscillator :

$$f_c = \frac{1}{2\pi\sqrt{LC}} \qquad (25)$$

where f_c = carrier frequency, C = varactor diode capacitance
L = inductance of the primary winding of T_1

❑ when a modulating signal is applied, the frequency is

$$f_c = \frac{1}{2\pi\sqrt{L(C+\Delta C)}} \qquad (26)$$

where f = new frequency
ΔC = change in varactor diode capacitance due to modulating signal

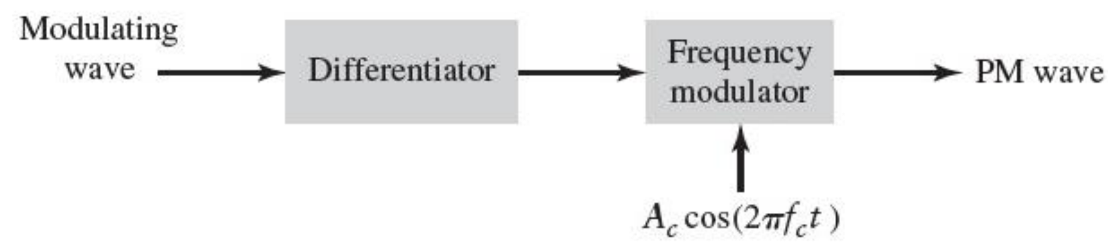
❑ the change in frequency is $\Delta f = |f_c - f|$ (27)

❑ where Δf = peak frequency deviation (hertz)

FM/PM Modulators

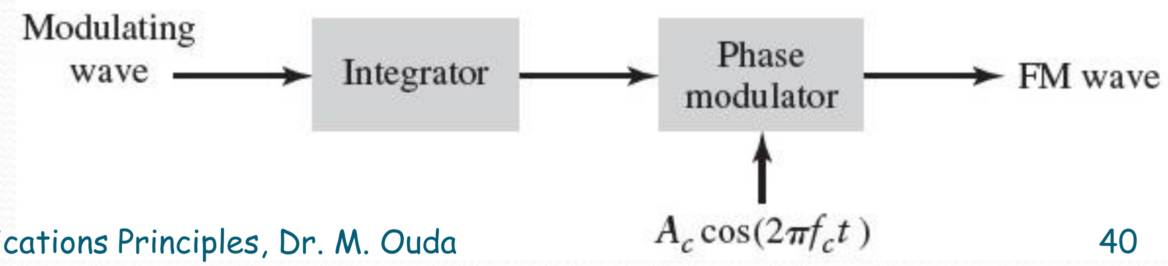
- if the modulating signal is *v(t)* is differentiate before being applied to the FM modulator, the instantaneous phase is now proportional to the modulating signal (i.e. PM modulator).

Differentiator + FM modulator = $\theta(t) \propto \int \frac{dv(t)}{dt} = \theta(t) \propto v(t)$ = **PM modulator**



- Meanwhile, if the modulating signal is integrated before being applied to the PM modulator, the instantaneous phase is now proportional to the integral of the modulating signal (i.e. FM modulator).

Integrator + PM modulator = $\theta(t) \propto \int v(t)$ = **FM modulator**



FM/PM Indirect Method Modulators

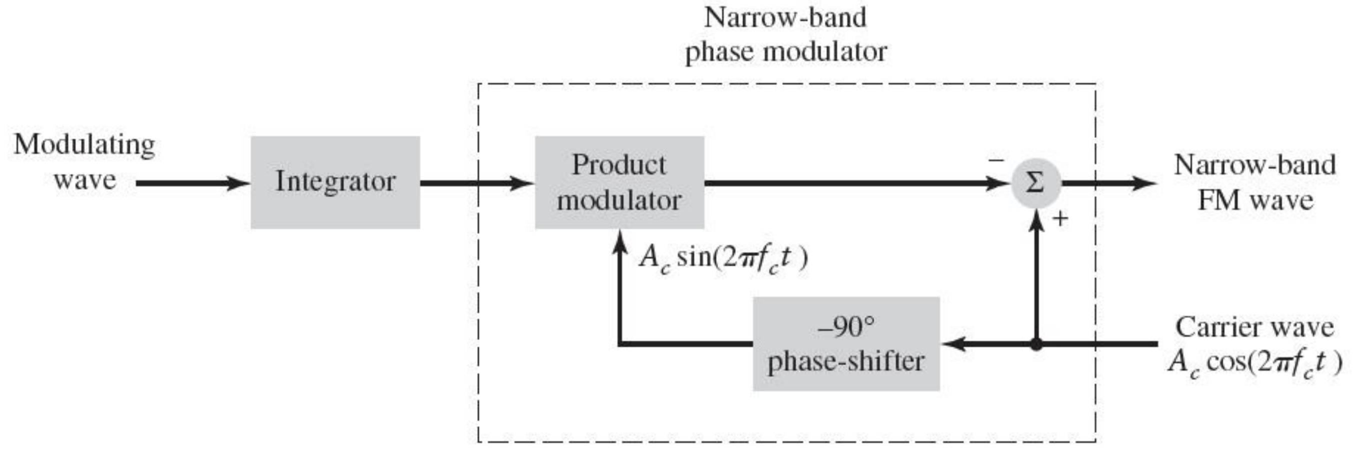


FIGURE 4.4 Block diagram of an indirect method for generating a narrow-band FM wave.

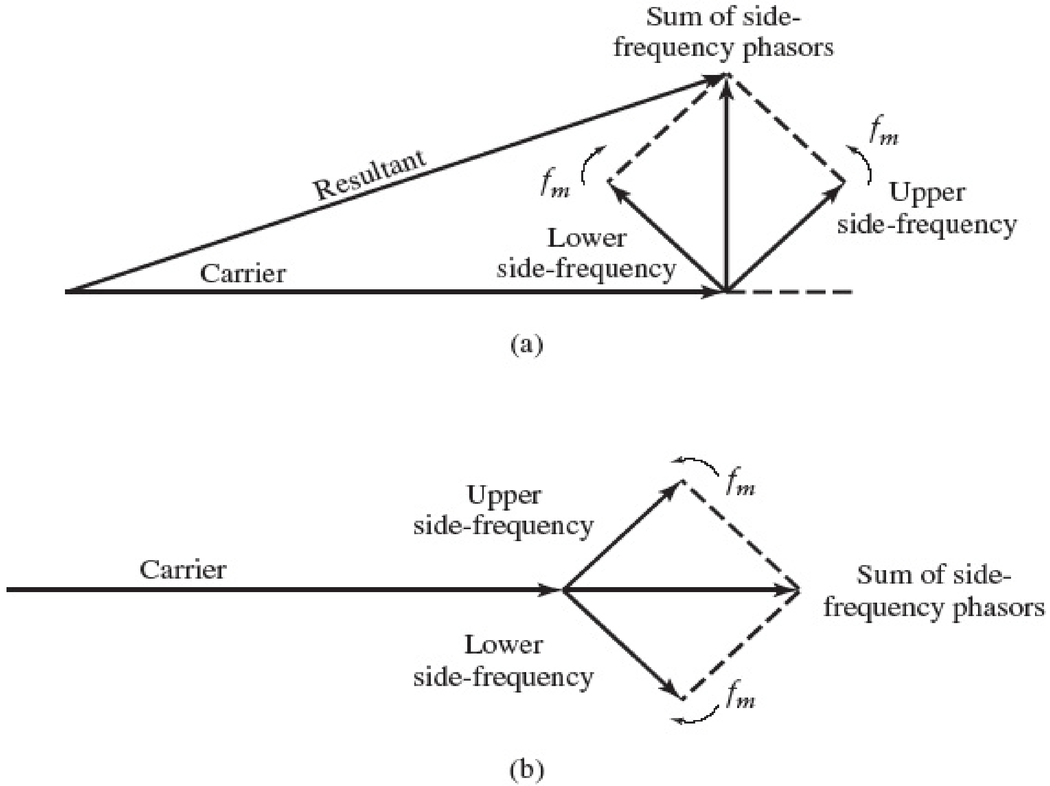


FIGURE 4.5 Phasor comparison of narrow-band FM and AM waves for sinusoidal modulation. (*a*) Narrow-band FM wave. (*b*) AM wave.

Armstrong wide-band frequency modulator

The carrier-frequency stability problem is alleviated by using a highly stable oscillator

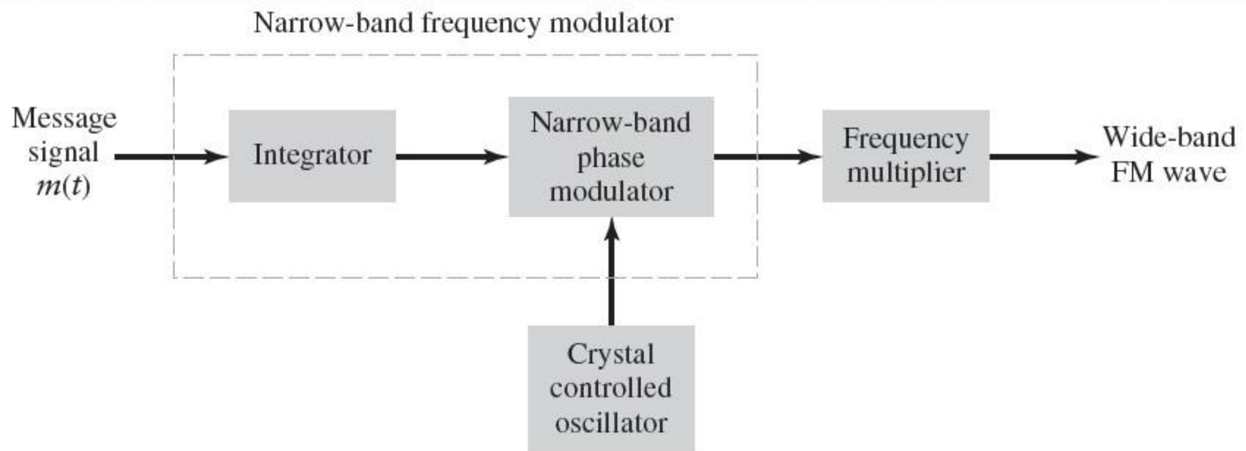


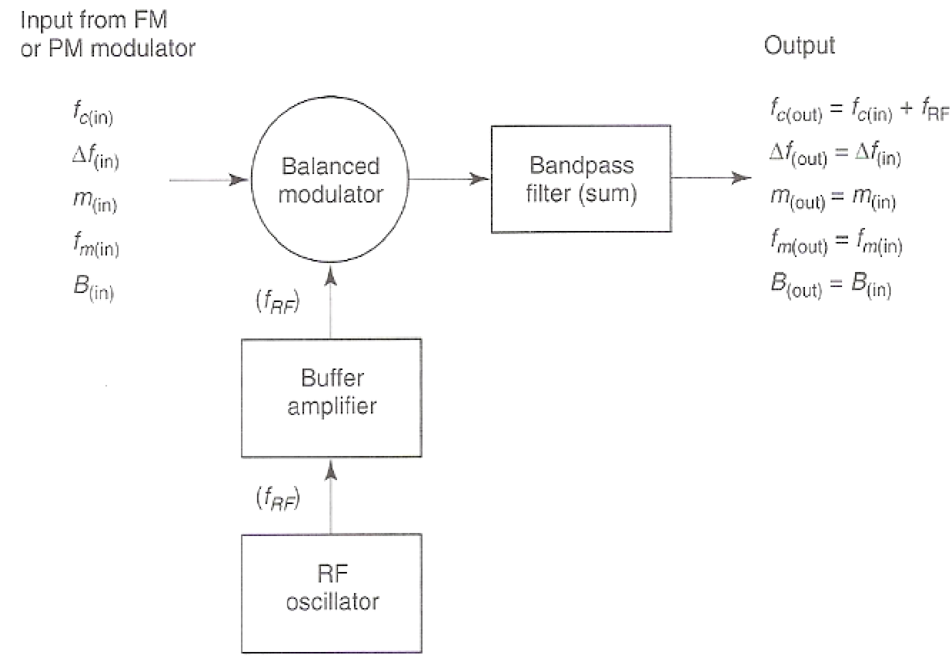
FIGURE 4.10 Block diagram of the indirect method of generating a wide-band FM wave.

Frequency Up-conversion

- ❖ after the modulation, the frequency of the modulated-wave is up-converted to the desired frequency of transmission.
- ❖ 2 basic methods of frequency up-conversion :
  - ❖ heterodyning process
  - ❖ frequency multiplication

Heterodyne Method

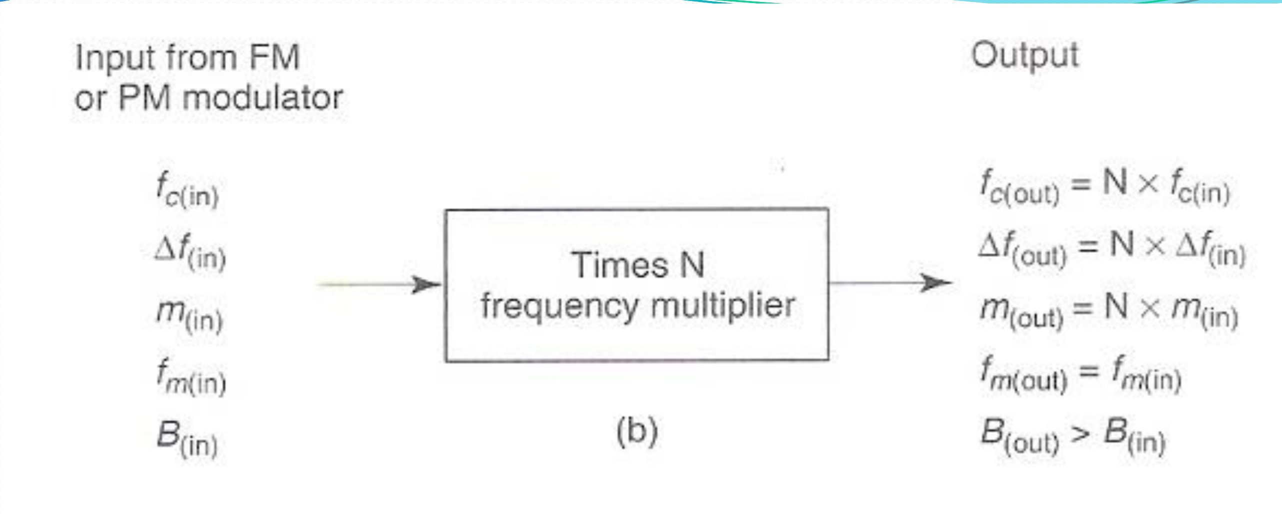
- 2 inputs to the balanced modulator : angle-modulated carrier and its side frequencies, an also the unmodulated RF carrier signal.
- the 2 inputs mix nonlinearly in the balanced modulator producing the sum and difference frequencies at its output.
- the BPF (bandpass filter) is tuned to the sum frequency with a passband wide enough to pass carrier plus the upper and lower side frequencies while the difference frequencies are blocked.



- the frequency deviation, rate of change, modulation index, phase deviation and bandwidth are unaffected by the heterodyne process.

$$f_{c(out)} = f_{c(in)} + f_{RF}$$

Multiplication method



- with multiplication method, the frequency of the modulated carrier is multiplied by a factor of *N* in the frequency multiplier.
- frequency deviation, phase deviation and modulation index are also multiplied.
- However, the rate of the deviation is unaffected (i.e. the separation between adjacent side frequencies remains unchanged).
- as frequency deviation and modulation index are multiplied, the number of side frequency also increases. Thus, the bandwidth also increases.
- For modulation index higher than 10, Carson's Rule can be applied

$$B_{out} = N(2\Delta f) = NB_{in}$$